Dec. 11, 1951 D. G. P. EBELING 2,578,407

METHOD OF MAKING CAST ALNICO MAGNETS

Filed Jan. 10, 1948

Fig. 1.

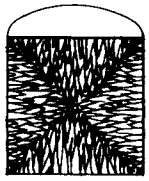


Fig. 2.

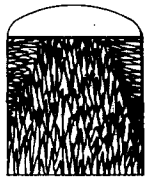


Fig. 3.

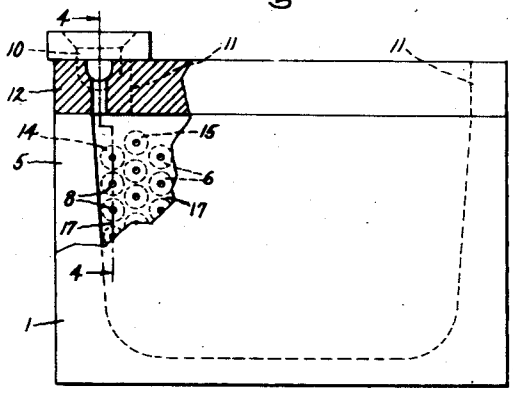


Fig. 4.

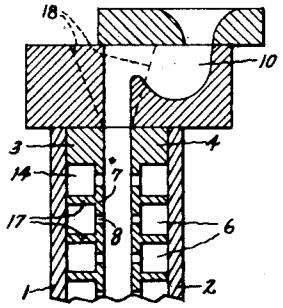


Fig. 5.

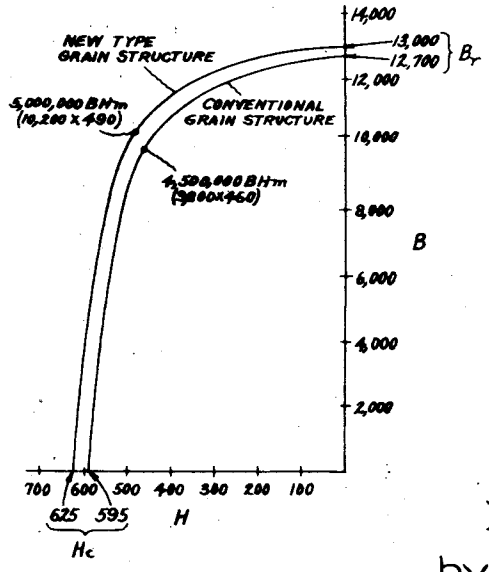
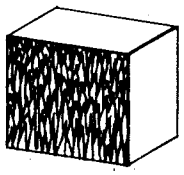


Fig. 6.



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Patented Dec. 11, 1951

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UNITED STATES PATENT OFFICE

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METHOD OF MAKING CAST ALNICO MAGNETS

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Application January 10, 1948, Serial No. 1,499

4 Claims. (Cl. 148—3)

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This invention relates to cast Alnico magnets. It is particularly concerned with a commercially useful method of casting iron-nickel-aluminum alloys which results in markedly improved magnetic properties along certain directions in the cast product. The term "directional properties" is used to describe the situation where the magnetic properties, such as the remanence, maximum energy, fullness factor, and coercive force, in one direction are appreciably higher than those measured in a direction perpendicular to this preferred direction.

It has been known for some years that it is possible to produce directional properties in cast Alnico magnets comprising certain alloys of aluminum, nickel, cobalt and iron by subjecting the solid castings to a heat treatment in a magnetic field. Such a process is described for example in Patent 2,295,082 Jonas wherein the direction of the heat treating field is made to coincide with the direction of final magnetization. The present invention relates to a further improvement in such directionally treated magnets which comprises casting these magnets in such a manner and under conditions such that the improvement in directional properties is still further and markedly enhanced over that produced by the magnetic heat treatment.

Various processes have also been proposed with the object of obtaining, during the cooling of the magnetic alloy, what has been termed the optimum dispersion hardening conditions. These processes have been based on the theory that by controlling the temperature conditions under which the dispersion hardening reaction takes place, improved magnetic properties could be obtained. For example, Patent 2,323,944, Snoek recommends that the heat treatment or cooling of the solid cast magnet should be under conditions such that at the commencement of the dispersion process there is a pronounced temperature gradient in the material in a given direction for the purpose of improving the magnetic properties of the final product. However, none of these prior attempts to improve the magnetic properties of cast alnico by control of the grain structure have been found to be of great value in the commercial production of anisotropic permanent magnets which were any better magnetically than those obtained merely by following only the teachings of the above-mentioned Jonas patent.

The present invention is based on the discovery that in order to obtain any substantial improvement in the properties of the anisotropic

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Alnico magnets it is necessary to control the macrostructure as well as the microstructure of the cast product and that, to accomplish this purpose, it is essential that the desired crystalline arrangement be created or formed in the as-cast structure, i. e., during solidification of the casting. In other words, it has been found that, in the commercial production of such magnets, emphasis must be placed on the cooling of the casting in the liquidus-solidus temperature range, the magnet being so designed and cooled that a major portion of the cast product is composed of long columnar grains whose axes extend parallel to the direction of final magnetization. Further, it is preferred that these directionalized columnar grains should be present throughout the entire distance between the pole faces of the cast structure and should comprise at least 60 per cent of the macrostructure of the cast material.

The desired conditions in the as-cast structure are obtained in accordance with the present invention by employing a molten iron alloy of the composition set forth in the Jonas patent, i. e., an alloy essentially containing from 16 to 30 per cent cobalt, 12 to 20 per cent nickel and 6 to 11 per cent aluminum, and controlling the cooling of the alloy in the liquidus-solidus region, which in turn controls the solidification of the liquid metal. If the relative cooling rates are properly adjusted by the suitable placement of chills or insulators, or both, and if the length-to-diameter ratio of the casting is not greater than 5 to 1, it has been found possible to control effectively the rate of growth of the crystals in the various directions to obtain a macrostructure imparting superior magnetic properties to the finished casting.

More specifically the magnets of the present invention are obtained by casting a molten iron-cobalt-nickel-aluminum alloy of the above type in a multiple cavity mold in which the cavities are of such size that the cast product has a length-to-equivalent diameter ratio of not more than 5 to 1 and preferably not more than about 2 to 1, the cavities being so arranged that solidification of the cast material by loss of heat to or through the side walls of the cavities is held to a minimum. Under these conditions and by the use of chills at at least one end of each cavity to remove the heat liberated during solidification there is obtained a temperature gradient lengthwise of the castings during solidification thereof which is sufficient to produce castings in which a major portion of the columnar grains extends

in a lengthwise direction. The terms "length" and "lengthwise" as used herein and in the appended claims have reference to the pole-face-to-pole face measurement along the longitudinal axes of the magnet and the term "equivalent diameter" is employed to cover castings of irregular cross section, the "equivalent diameter" of which would be the diameter of a circle having the same area as the average cross-sectional area of the cast piece.

The ability to control the crystal orientation of castings appears to be highly beneficial in the casting of magnetic alloys, since the magnetic properties of the crystals are so markedly different in the different crystallographic directions. In the case of the subject alloys, it has been found that the direction of greatest grain growth velocity (100) is also characterized by a high remanence and a very full demagnetization curve. These two prominent effects combine, along with a slightly higher coercive force, to give in the cast product a very significant increase in the maximum available external energy, that is, the maximum area under the hysteresis curve in the second quadrant. These changes in the magnetic properties are illustrated in Fig. 5. Consequently, the primary object of the present invention is to design the cast magnet below a certain length-diameter ratio and to cast the magnetic alloy in such a manner that the cooling direction is properly adjusted during solidification of the cast alloy, so as to control the growth, and thus the relative amounts of the differently oriented columnar grains; this control of the macrostructure making it possible to set up a predominantly favorable crystallographic orientation throughout the casting.

For a more detailed description of the present invention, reference is made to the following description thereof and to the accompanying drawing in which Fig. 1 illustrates the macrostructure of a cast magnet prepared by presently used casting methods; Fig. 2 illustrates the grain structures of cast magnets prepared in accordance with the present invention; Fig. 3 is a view partially in section of a multiple cavity mold for use in casting the improved anisotropic magnets; Fig. 4 is a partial sectional view of the mold along line 4—4 of Figure 3; Figure 5 shows demagnetization curves comparing the product of the present invention with the presently available magnets; and Fig. 6 illustrates the grain structure of an ideal magnet.

Figure 1 shows the macrostructure of a cylindrical casting of an aluminum-nickel-cobalt iron anisotropic permanent magnet of the composition and shape now commonly used in loud speaker systems which during casting has been cooled to the solid state evenly from all sides. The illustrated condition is realized when the heat of solidification is extracted at the same rate from all external surfaces as would occur when casting a single magnet in the usual thick sand core. It will be noted that the columnar grains grow inwardly perpendicularly from the mold walls. In this case, since the rates of growth from all sides are approximately equal, the parting lines that separate the regions of differently oriented, columnar grains are practically straight lines which intersect in the center of the magnet. Actually, the lines in this figure are sections of a cone of revolution having an apex at the center of the magnet and bases coinciding with the ends of the magnet. As such magnets are normally magnetized in a direction parallel to the axis of the magnet, only about 33 per cent of the volume of the casting is composed of favorable oriented grains.

A much more desirable grain orientation is that shown in Fig. 2 in which over 60, specifically about 68 per cent of the grains are favorably oriented as the result of extracting a major portion of the heat of solidification from one end of the magnet by a chill member of high heat capacity and conductivity. The following is an example of a production method for casting such magnets in accordance with the present invention employing a casting apparatus comprising a particular assembly of baked sand cores and chill plates by means of which as many as 236 one-inch diameter magnets have been cast successfully without any magnetic rejects.

As shown in Figs. 3 and 4, the assembly comprises two metal face plates 1 and 2, two baked sand magnet molds 3 and 4 and a hot well frame 5. The magnetic cavities 6 are molded into the face of the sand core opposite the hot well with a thin wall 7 of sand at the back end of each cavity. In each wall 7 there is a small circular gate 8 which serves to feed the cavity. Two of these cores are placed on edge so that the backs of the cores are separated by the "hot well" frame 5 which is also a baked sand core. The metal plates are clamped over the open faces of the cores and the metal is poured into the center hot well through pouring spout 10 in one end of cope 12. From here it flows through the gates into the individual magnet cavities. Porosity in the top row of magnets due to shrinkage is avoided by the presence of a tapered hot top molded into cope 12, the end walls of this hot top being indicated by numeral 11 in Fig. 3 and the side walls by dotted lines 13 in Fig. 4.

As shown in Fig. 3 the magnet cavities 6 are very closely spaced in a honey-comb pattern; this arrangement serving to prevent to a substantial extent the loss of heat through the side walls and thus accentuating the directional cooling provided by the metal face plates. More specifically, the cavities are so positioned in the mold cores 3 and 4 that each cavity is surrounded or substantially surrounded by adjacent cavities so that no substantial amount of heat is lost through the walls of any particular cavity to any large volumes of sand in the neighborhood thereof. While of necessity certain of the cavities such as the corner cavities 14 and 15 are not entirely surrounded by adjacent cavities, in the arrangement shown even these have neighboring cavities over some 210° or about 60% of their perimeters. This protection has been found sufficient to obtain the desired anisotropic crystal structure. Thus, by employing the illustrated casting assembly the necessary insulating and cooling conditions can be obtained in all of the castings without resorting to the use of additional runners for example in these parts of the core surrounding the cavities so as to prevent undue cooling of the outermost castings.

Preferably the layers of sand forming the partitions 17 between adjacent cavities and the walls 7 forming the ends of the cavities next to the hot well are made as thin as possible consistent with the strength requirements of the mold. Ordinarily, the thinnest sections of these parts of the mold should be not over one-quarter inch, usually from one-eighth to one-quarter inch thick.

The face plates 1 and 2 which are preferably steel plates are of a thickness and volume such that the heat capacity thereof is sufficient to ef-

fect the desired chilling of the melt during solidification thereof. By thus maintaining a temperature gradient in each cavity in a direction normal to the surface of the chill plate, long columnar crystals are formed during solidification of the alloy with the major axis of these crystals oriented predominantly in a direction normal to the surface of the chill. As soon as the castings have solidified the face plates can be removed and the castings cooled with air, for example by means of an air blast.

Employing this apparatus, a full scale production experiment was carried out in which magnets cast as described herein were compared with magnets cast in the usual sand molds and having the grain structure shown in Fig. 1. The alloy employed was a preferred alloy known as Alnico V and consisted essentially of about 8% aluminum, 14% nickel, 24% cobalt, 3% copper, balance substantially iron. All of the magnets were cast from the same heat, each magnet was carefully identified, and then both types of magnets were heat treated in accordance with the Jonas patent at the same time by placing the two types of magnets in alternate positions in the heat treating boats. A total of 236 pairs of magnets, one of each type, were treated. By this procedure, all variables other than the difference in grain structure were eliminated. The results of tests made on all these magnets are as follows:

Grain Structure	Average Maximum Energy BH max.
As shown in Figure I	4,470,000
As shown in Figure II	4,950,000

Thus, the test results on these 236 pairs of otherwise identical magnets show that the magnets having grain structure as shown in Fig. 2 had a maximum energy value that was 480,000 gauss-oersteds greater than those having the structure of Fig. 1. The importance of this grain structure effect has been demonstrated even more graphically by experiments conducted during the course of the development of the aforedescribed production method. For example, a much larger cylindrical casting was made using the same general principles and techniques described above and then smaller cubical specimens, approximately 1" in size, were cut from the center of the original casting in such a way that it was composed exclusively of long columnar grains extending in only one direction which was parallel to a cube edge. The grain structure of these cubes is shown in Fig. 6. A set of these magnets was treated in a magnetic field according to the Jonas patent such that some of the magnets were oriented so that the long axes of the columnar grains were either parallel with or perpendicular to the direction of the magnetic field applied during the heat treatment. The magnetic test results on these specimens are summarized in the following table:

Direction of Long Axes Columnar Grains	Is	Br	H_c	$f=\frac{BH_{max}}{BrH_c}$	BH_{max}
Perpendicular to Field	14,000	13,000	640	.65	5,400,000
Parallel with Field	14,100	13,300	700	.69	6,400,000

Thus, the very potent effect of the proper columnar grain orientation is amply demonstrated and these results point out that the degree of improvement in magnetic properties is a direct function of the degree of grain alignment that was originally created in the cast magnet.

The above described commercial method of improving the performance of permanent magnets depends upon the control of the crystallization process so as to produce a casting which is composed of columnar grains whose long axes are parallel to the direction of final magnetization. If the shape of the magnet is such that it has a large length-to-diameter ratio, and the magnet is to be magnetized along its length, then it will be increasingly difficult to obtain the most favorable grain structure as the length increases. However, most magnets that have commercial application have a length-to-"equivalent diameter" ratio less than 5:1, and the principles of this invention will apply in these cases.

While the invention has been specifically described with reference to a preferred Alnico composition, it is to be understood that it is not limited thereto. However, to obtain the desired results, that is, a permanent magnet having BH max. and fullness factor values substantially greater than those of previous known permanent magnets of the Alnico type, it is necessary to employ alloys containing about 16 to 30 per cent cobalt, 12 to 20 per cent nickel, 6 to 11 per cent aluminum and the remainder principally iron. Copper may advantageously be present in amounts up to 5 per cent and titanium in amounts not over 5 per cent. The effect of these elements and others on the base composition is set forth in the above-mentioned Jonas patent.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. The method of manufacturing a magnetically anisotropic cast permanent magnet which comprises forming a melt of a ferrous alloy containing about 16 to 30% cobalt, 12 to 20% nickel, 6 to 11% aluminum and the remainder principally iron, casting said melt in the form of a body having a length-to-equivalent diameter ratio of not over 5:1 and while preventing to a substantial extent the loss of heat from the sides of the molten body of alloy effecting the solidification thereof by extracting a major portion of the heat of solidification of said alloy from only one end of the cast molten alloy by means of a metal chill in direct contact with the molten alloy, said chill having a heat capacity sufficient to maintain a temperature gradient lengthwise of said body thereby to form long columnar crystals during solidification of the alloy, which crystals extend lengthwise and along the entire length of the solid product and form at least a major portion of the macrostructure thereof, and heat treating the solid product in a magnetic field with the longitudinal axis of the solid product parallel to the direction of magnetization.

2. The method of manufacturing a cast anisotropic permanent magnet which comprises forming a melt of a ferrous alloy containing about 16 to 30% cobalt, 12 to 20% nickel, 6 to 11% aluminum and the remainder principally iron, casting said melt in the form of a body having a length not substantially exceeding five times its equivalent diameter with only one end in contact with a chill and the other end and all sides of the body surrounded by masses of the molten alloy in closely spaced relationship to said body whereby during cooling of the molten body of alloy to a solid state said chill effects a temperature gradient lengthwise of said body sufficient to form in the solid product a major portion of long columnar grains extending lengthwise of said body

throughout the entire length thereof, and magnetizing the cast solid product with said long columnar grains parallel to the direction of magnetization.

3. The method of manufacturing a magnetically anisotropic magnet which comprises forming a melt of about 6 to 11% aluminum, 12 to 20% nickel, 16 to 30% cobalt, up to 5% copper, balance substantially iron, casting said melt in the form of a body of molten alloy having a length not exceeding five times its equivalent diameter with one end thereof in contact with the surface of a chill of high heat conductivity and capacity, and the other end and the side walls surrounded by additional masses of said melt in closely spaced relationship to said body so that there is obtained during solidification of said melt a temperature gradient lengthwise of said body by the extraction of a major portion of the heat of solidification of the molten alloy by said chill with the resultant formation of an anisotropic grain structure in which long columnar grains extend lengthwise along the entire length of the solid product over at least 50% of the cross section thereof, and magnetizing the solid body in a lengthwise direction.

4. The method of manufacturing a magnetically anisotropic cast permanent magnet which comprises forming a melt of a ferrous alloy containing about 16–30% cobalt, 12–20% nickel, 6–11% aluminum and the remainder principally

iron, casting said melt in the form of a body and while preventing to a substantial extent the loss of heat from the sides of the molten body of alloy effecting the solidification thereof by extracting a major portion of the heat of solidification of said alloy from only one end of the cast molten alloy by means of a metal chill in direct contact with said end of the molten alloy, said chill having a heat capacity sufficient to maintain a temperature gradient in a direction normal to the surface of said chill thereby to form long columnar crystals during solidification of the alloy with the major axis of the crystals oriented predominantly in said direction and forming at least a major portion of the macrostructure, and heat treating the solid product in a magnetic field with the major axis of the crystals parallel to the direction of magnetization.

DOLPH G. P. EBELING.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
741,460	Chantraine	Oct. 13, 1903
1,947,274	Ruder	Feb. 13, 1934
1,989,551	Faus	Jan. 29, 1935
2,156,019	Jonas	Apr. 25, 1939
2,398,018	Linley et al.	Apr. 9, 1946